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USE OF LOW EARTH ORBIT SATELLITES FOR VOICE COMMUNICATIONS

Note by the Secretariat

1. The Working Group of the Whole to Evaluate the Implementation of the Recommendations of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 82), at its seventh session (A/AC.105/543, annex II, para. 17), recommended that several studies on space applications should be carried out to demonstrate the potential of space technology. The Working Group of the Whole identified a number of possible subjects for such studies, including the use of low Earth orbit (LEO) satellites for communications.

2. The report of the Working Group of the Whole was adopted by the Scientific and Technical Subcommittee at its thirtieth session (A/AC.105/543, para. 22), and the recommendations contained in the report were endorsed by the Committee on the Peaceful Uses of Outer Space at its thirty-sixth session[1] and by the General Assembly in its resolution 48/39 of 10 December 1993.

3. In response to the request of the Working Group of the Whole, the Secretariat prepared a study on the use of LEO satellites for voice communications. The study, which is available in English only, is presented in the annex to the present note. The purpose of the study was to provide a review on the applications of LEO satellites for voice communications, primarily for the benefit of countries that had not yet used that technology but were interested in its potential benefits. The study was prepared using a variety of national and international sources, which are listed in the selected bibliography at the end of the study. A summary of the study is provided below.

SUMMARY OF THE STUDY

4. In recent years there has been renewed interest in utilizing small satellites in low Earth orbits (LEO) to provide various types of services, ranging from low-speed data transmission to voice communications, especially for cellular telephony. This interest has been generated because of the increasing cost and long lead-time cycles involved in the use of geostationary satellites. Small satellites launched into low-altitude circular orbits are often a better alternative because of the lower cost of the satellite itself and lower launch costs. Some LEO systems could be used, for example, for emergency alert, alarm signals, position location for fleet movement, remote sensing, telemetry, data collection and environment monitoring, paging, short

recorded message formats, radiodetermination and data networking. This survey, however, is limited to a brief description of the principal LEO systems, which are sometimes referred to as the "big" LEO systems. These are the Iridium, Ellipso, Globalstar, Odyssey and Project 21 systems. All these systems would have a space segment, composed of 12-66 satellites and would provide voice and high-speed data, relay, radiodetermination and a wide range of other services. It should be noted that the present study contains a discussion of only the provision of voice communications by the "big" LEO systems mentioned above, and not the other services they would provide.

5. The use of radio-telephones is just the first stage in a broad shift towards wireless personal communications. Although cellular communications networks are expanding and will continue to do so, economics prevents them from spreading much beyond populated areas. The astonishing improvements in microcircuits over the past decade have made possible the packaging of an entire satellite Earth station into a hand-held telephone. The implementation of an increasing number of personal mobile satellite communication services throughout the 1990s will expand the nature and the scope of mobile satellite communications from services designed principally for relatively small market niches to a utility that will be attractive to considerably larger, worldwide markets. These satellite services provide an important complement to terrestrial mobile services because they can reach areas that are too remote to make service via other means economically viable. These services also provide a global standard that can operate across regions of different, and incompatible, standards.

6. A World Administrative Radio Conference (WARC 92) was held at Torremolinos, Spain, from 3 February to 3 March 1992. One of the conclusions of WARC 92 was that implementation of LEO satellite systems could lead to the development of hand-held telephones for use in remote areas throughout the world. This new trend in satellite communications has created many new policy, legal, economic and technical issues that need to be addressed. Various proposals for satellite personal communications systems and services foresee the use of circular low and medium Earth orbits, highly elliptical orbits or geostationary orbits. Some of these were discussed in detail at WARC 92 under the general heading LEO systems, though some of the systems clearly envision the use of other orbits. The proposal for one geostationary orbit system envisioned the current generation of mobile satellite systems evolving into personal satellite services.

7. Communications via satellite personal mobile communication systems are established by connecting the satellites to the end-users, if necessary by existing terrestrial networks. The systems proposed vary in their technical parameters, as well as in their estimated costs, which range from US$ 0.5 billion to US$ 3.5 billion. The bulk of these costs would result from the manufacturing and launching of the satellite constellations. The handsets would most likely cost anywhere from a few hundred dollars (comparable to existing cellular receivers) to US$ 3,500 for the most sophisticated ones. Due to these varying system cost estimates, preliminary user price estimates for each minute of calling time vary considerably, from US$ 0.33 to US$ 3 per minute. The actual costs may be higher.

8. Potential user groups for LEO personal satellite communications systems might include persons attached to government agencies, commercial users, fleet managers, owners of land and water vehicles, business travellers, and persons providing emergency or transportation services. Government agencies will benefit from two-way voice communication and position location capabilities in such areas as disaster relief, law enforcement, air traffic control, resource management and weather reporting. Commercial uses might be found for the proposed LEO systems in, for example, rural facilities that are not served by existing public switched telephone networks (PSTN) or cellular networks. Utilities that require regular but infrequent monitoring, security services and resource management systems are also potential users. Potential fleet management uses include areas such as interstate trucking, passenger buses, rail freight and inland waterways. In addition, travel services provide a natural market for LEO system service, including global paging, recreational activities, public communication, shipping, general aviation and emergency services.

9. The proposed Iridium system is a digital communications system that would operate in a cellular communication architecture. The planned constellation of LEO satellites would cover the Earth with beams turned on and off as required to ensure global coverage. The emphasis in the Iridium programme would be on the personal communication device, the handset. It would be pocket-sized, would run on rechargeable batteries and would be capable of operating in environments typical of today's cellular telephones. The planned satellite constellation would be comprised of six polar-orbital planes; as each plane would contain 11 operational satellites, the total constellation would be comprised of 66 satellites.

10. The Iridium system would be an upside-down cellular system. In traditional cellular networks, the infrastructure is on the ground, the cells are fixed and the user moves through them. With Iridium, the infrastructure would be in space, the cells would rotate across the Earth as the planet spins, and the user could be regarded as stationary, relative to the speed of satellites. Strictly speaking, Iridium would not really be a space system, but rather a communications system that would happen to have some of its infrastructure located in space. The satellites would be networked together through inter-satellite links that would form an interlocking, seamless web. Each satellite would utilize state-of-the-art phased array antennas to generate 48 separate spot beams. These beams would form the terrestrial cells.

11. A variety of end-user products would be developed for communications via the Iridium system. These user products would include hand-held and mobile telephones (single and dual mode), solar-powered phone booths, specialized aeronautical and marine units and a variety of paging products. Each user product would provide one or more of the planned system user services. These include voice, data, facsimile and position location. The Iridium user could call any telephone number on Earth and be connected almost instantly to the appropriate land line, mobile cellular or other Iridium phone.

12. The proposed Globalstar system would be comprised of a constellation of 48 LEO satellites in circular orbits, in eight orbital planes. Each satellite would operate as a simple frequency translating repeater in space, thereby eliminating complex set-up procedures and on-board processing. The system would be configured so that a mobile user would be linked to a terrestrial gateway directly through individual satellites, thereby eliminating the need for satellite traffic crosslinks. Each satellite would communicate with the mobile user via satellite-user links and with gateway stations directly via feeder link. There would be many gateway stations distributed throughout the world. Each country could have its own independent gateway(s) and could have control of system access by users within its own boundaries.

13. During the initial phase of the Globalstar network, there would be two kinds of user equipment. These would be based on small, omnidirectional antennas and would include hand-held terminal units for voice and radiodetermination satellite services (RDSS) and vehicle-mounted and fixed units for RDSS-only terminals. Billing would be based on circuit-time usage and type of service. Voice calls would be charged from the time the call is answered until the circuit is released. Service charges for data transmission would be based on the amount of bits transmitted, which is equivalent to the amount of time network interfaces are used.

14. The proposed Ellipso system would provide telecommunications services throughout the world to users who currently are not served at all or are poorly served by existing mobile and fixed telephone systems. To accomplish this, Ellipso would use LEO satellites to reach its subscribers directly at a price that would be competitive with terrestrial telephone service prices, approximately US$ 0.50 per minute. Ellipso would offer the user not only mobile telephone services, but also other digital services, such as data transfer, facsimile, paging, voice mail and messaging. The Ellipso system would not bypass existing telephone systems in offering these services but would extend their areas of coverage.

15. The Ellipso system would be unique in that it would split global coverage into two zones roughly divided by the tropic of Cancer. Northern coverage would be provided by the northern part of the system, which would use up to 18 satellites in inclined elliptical orbits in several planes. These elliptical orbits would be

chosen so that the satellites would spend a majority of their orbital rotation period north of the equator, where they could provide service for a greater percentage of their orbits than if circular orbits would be used. Additional orbits and satellites in the constellation would extend coverage to tropical and southern latitudes. Ellipso would utilize simple transponder satellites and electronic processing functions would be performed in the terrestrial stations. The Ellipso user terminal would be comparable in form to those currently used for cellular telephony. In fact, Ellipso communications would be designed to facilitate seamless switch-overs from terrestrial cellular to Ellipso communications when cellular systems become unavailable to the user.

16. The Odyssey satellite communications system is intended to provide high-quality wireless communication services from satellites. These services would include voice, data, paging and messaging. The goal of the Odyssey system would be to provide an economical design approach to providing communications. To provide continuous coverage of designated regions, a constellation of 12 satellites would be orbited in three inclined planes of 10,000 km. This system would provide a link between mobile subscribers and PSTN via dedicated ground stations in each region. Long-distance calls would be directed to the designated long-distance PSTN in the gateway region. The gateway stations would also provide all the signal processing for the Odyssey system.

17. For setting up calls with the Odyssey system, priority would be given to the use of terrestrial cellular services. All communication processing would be performed on the ground, which would allow the use of a less complex satellite payload. The goal would be to provide service for US$ 0.65 per minute. The system would provide high-priority service for premium customers who require reliable mobile communications via a small hand-held terminal. Subscribers could have a single telephone that would go with them and that would not require special access codes.

18. Project 21, the personal communication strategy of the International Maritime Satellite Organization (INMARSAT), represents the evolution of personal mobile satellite services, which the organization has been introducing throughout the 1990s. In the framework of Project 21, INMARSAT-P, a global hand-held satellite phone, would most likely be introduced by the end of the decade. The basic objective of the INMARSAT-P service is to provide telephony to and from hand-held terminals with an unobstructed satellite view, and with voice quality similar to that of digital cellular systems. The INMARSAT-P phone would incorporate a dual-mode feature: it would operate as a normal cellular phone when within range of a cellular system; otherwise, it would operate as a satellite phone. Calls could be made to or received from any phone on the PSTN or other mobile satellite terminal.

19. INMARSAT has eliminated the possibility of using a LEO constellation for Project 21. The organization is currently in the process of determining whether the flexibility and reach of a constellation of spacecraft in intermediate orbits would be less complex and more cost-effective than a constellation of several larger satellites in geostationary orbit. For intermediate circular orbits at an altitude of about 10,000 km, INMARSAT is studying a constellation of 12-15 satellites. For geostationary orbit over the equator, INMARSAT is considering a five-satellite system. Both options would provide global coverage. The general design concept behind Project 21 is to make maximum use of existing terrestrial network trunks and technologies to ensure a cost-effective and flexible network design. INMARSAT members have access to comprehensive terrestrial network trunks, and the majority of international telephony traffic by the year 2000 would utilize fibre optic cables, which would offer a flexible, high-performance and cost-effective means of routing traffic around the globe. The goal of the project is to impose space segment charges of about US$ 1 per minute for voice communications. This would compare favourably with end-user charges of US$ 5-6 per minute for current services.

Note

[1]Official Records of the General Assembly, Forty-eighth Session, Supplement No. 20 (A/48/20), para. 25.

Annex

USE OF LOW EARTH ORBIT SATELLITES FOR VOICE COMMUNICATIONS

Study by the Secretariat*

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INTRODUCTION

A. Communications and development

1. Today, practically every country in the world benefits from a variety of communication services through participation in international, regional and domestic satellite systems. Indeed satellite communications technology is now recognized as a critical tool for social and economic development as advances in the technology continue to lower the costs of its utilization.

2. Satellite communication services continue to find commercial applications in the distribution of space-acquired data, supercomputer networks, mobile services, broadband Integrated Services Digital Networks (ISDN) and a variety of information services in every practical aspect of human endeavour. The use of techniques such as onboard data processing, efficient network protocols and effective miniaturization would improve the cost competitiveness of future satellite systems.

3. Communication satellites epitomize the reality of two phenomena: "the global village" and the "information age." Satellites can bring the power of information to virtually everyone on Earth and can enable its inhabitants to instantaneously share experiences. Yet humanity still has much to learn about the effects of this technology. For example, satellites have the potential to eliminate the barriers of distance that have hampered economic growth and delivery of social services in rural and remote regions of both industrialized and developing countries. Humanity must learn how satellites can be used to increase rural residents' access to information, to raise agricultural productivity, and to promote the development of other rural industries. The extent to which the availability of satellite communications for high-quality voice and data communications can encourage other industries to decentralize their operations away from major cities must also be examined.

4. In many developing countries, where terrestrial systems are underdeveloped or even nonexistent, satellite communications services are particularly important. Internationally, satellites have the power to bring about a "global village." There is much still to be learned about the impact of global television on the knowledge and attitudes of viewers in various countries. Perhaps the most significant contribution of satellites will be to bring basic communications to people in developing countries. Smaller and cheaper earth stations, many of them solar-powered, coupled with new and improved radio technologies, should make it possible to reach virtually every human settlement. Yet developing countries will still face decisions about how to invest their limited resources to improve their basic infrastructure, including communications, transportation, electricity and water supplies.

5. More people are demanding communication services no matter where they are. Today, the number of cellular telephone users worldwide is about 18 million. By the year 2000, this may increase to more than 400 million. This is illustrated by the enormous demand for communications mobility in the mobile communications market over the past decade. Global personal mobile satellite services provide the key element, overcoming the inherent local or regional nature of terrestrial mobile services. The user of telecommunication services does not care if the service is delivered via satellite, mobile or fixed transmitters, or fiber optic cables. Ultimately, users just want to be connected wherever and whenever they want. Digital technologies are the keys to success in providing new ways to meet the future needs of these users.

6. The use of radiotelephones is just the first stage in a transition toward wireless personal communications. Although cellular and personal communications networks are expanding and will continue to do so, economic reality prevents their spread much beyond populated areas. Rural areas, regions of low population density within industrial countries and large parts of the developing world are destined to be underserved or remain completely out of reach of terrestrial mobile services. For example, in those areas of

the United States where there is existing wireline service, the cost of adding a new user to the system (the "last mile" to the user's home) is approximately $1,800. If the old cable is being replaced, this cost increases to $2,000. The cost per user for an area of the world where no wireline communications service exists would be much higher. Clearly wireless communications are the only realistic answer to the problem of proving service to such areas. Global mobile satellite services are particularly suited for extending the reach of cellular services, filling in gaps in terrestrial mobile coverage and providing the means for travellers to remain in contact no matter where on the Earth they may roam.

7. Satellite technology has become an essential world resource. Each nation has and will continue to apply this technology in ways best suited to meet its own unique requirements. Without satellite technology, though, high quality communications services would not be available globally and sustained economic growth cannot occur without high quality, globally available communications.

8. Preliminary market forecasts suggest that the number of personal mobile satellite communications users worldwide will likely rise to over one million by the year 2000 and could approach two to three million early next decade. The equipment needed for personal mobile communications is a portable, inexpensive terminal device with low power consumption that is compatible with terrestrial cellular systems. The associated ground-segment infrastructure must be able to support satellite-phone service on a stand alone and global basis as well as in a national/regional cellular extension mode.

9. The development and implementation of an increasing number of personal mobile satellite communication services throughout the 1990s will expand the nature and the scope of mobile satellite communications from services designed principally for relatively small niche markets to a utility that will attract considerably larger, worldwide markets. These satellite services provide an important complement to terrestrial mobile services by furnishing a global standard that can operate across regions of different and otherwise incompatible standards to give access to areas where terrestrial mobile services either do not or cannot reach economically. An important consideration is to ensure that personal mobile satellite communication services function with other existing and evolving communication systems as an integral part of the worldwide communications infrastructure.

B. The development of LEO satellite communications systems

10. Although satellites in geostationary orbit have around 300 applications, there has been a renewed interest in recent years in utilizing small satellites in low Earth orbits (LEO) to provide various types of services, ranging from low speed data to voice communications, especially for cellular telephony. This interest is due to the growing difficulties of using geostationary satellites such as increasing costs, long lead-time cycles, etc. For these reasons, small satellites launched into low altitude circular orbits are often a better solution because both the costs of the actual satellite and of placing it into orbit is less than that for larger geostationary orbit satellites.

11. Some LEO systems now under consideration would provide emergency alert signals, alarm signals, position location for fleet movements, remote sensing, telemetry, data collection and environmental monitoring, paging, short recorded message formats, radiodetermination (location) and data networking. Allocations for these services have been made in the Very High Frequency (VHF) bands where technology components are well developed.

12. A World Administrative Radio Conference (WARC-92) convened in Torremolinos, Spain and held from 3 February to 3 March 1992, arrived at some conclusions that might result in the implementation of LEO satellites systems that, in turn, could accelerate the development of hand-held telephones for use in unserviced and remote areas of the world. Such applications are important, not only for two-way voice or recorded messages, but also for new low cost satellite services such as position location, telemetry, data

collection, etc. They can also significantly expand space service uses, including television and radio broadcasting, fixed and mobile communications, space research, and inter-satellite services. WARC-92 allocated several frequency bands to mobile satellite services within which LEO systems could operate. Thus, there is a possibility that by the end of the millennium, more LEO satellites could be launched into orbit than all previous geostationary satellites launchings combined.

13. Various proposals for personal satellite communications systems and services, (presented in some detail at WARC-92 under the not entirely correct heading of LEO Systems), foresee the use of circular low, and medium Earth orbits (MEO), highly elliptical orbits, or geostationary orbits. In cases where the satellites will not be in geostationary orbits, the satellites would move relative to the Earth and the communications links might therefore need to be passed from satellite to satellite. The one proposed system that does utilize the geostationary orbit represents the planned evolution of the current generation mobile satellite system towards the use of personal satellite services.

14. This technical study is limited to a short description of the principal proposed LEO systems: Iridium, Ellipso, Globalstar, Odyssey and the International Maritime Satellite Organization's (INMARSAT) Project-21 system. These systems are sometimes referred to as the "Big" LEO systems because they are based on space segments with anywhere from 12 to 66 satellites that will provide for voice and high speed data, relay, radio determination and a wide range of services. As indicated by the title of this report, only one type of service that these systems will provide -- voice communications -- is covered here.

15. Rapid changes in satellite communication technologies and service trends have created many new policy, legal, economic and technical problems that need to be solved in order for these proposed systems to operate effectively. Decisions on frequency allocation, made at WARC-92 should enable at least two global LEO systems to begin operations as early as 1997. This would, of course, be subject to international coordination in order to avoid interfering with other services. It is clear that the possibility of having hundreds LEO satellites has raised many issues such as adequate frequency allocations, interference between LEO and existing geostationary satellite systems, the bypassing of terrestrial communications systems, etc.

16. Astonishing improvements in microcircuitry have been made during the past decade and these have made it possible to package an entire satellite earth station into a hand-held telephone. With this breakthrough has come another dramatic shift in the satellite paradigm: a personal telephone with an omnidirectional antenna does not require a stationary ground track of a geostationary satellite.

17. Significant advances have also been made in spacecraft computing capacity and data storage. It is now possible to place almost one billion transistors on a single integrated chip. Very Large Scale Integrated (VLSI) chips can now perform complex communications and logic functions at a fraction of the weight and power of previous technology. This enables greater spacecraft autonomy and allows large amounts of error correcting data storage capacity to be built into a satellite. The development of efficient gallium arsenide and indium phosphide solar cells has facilitated greater power output with smaller arrays and advanced composites provide strong, lightweight structural materials.

18. These and other developments have had a significant impact on the design of space systems. First, miniaturized components now allow very capable space systems to be constructed at a fraction of the size and weight that has historically been required to achieve comparable capabilities. This reduces materials, assembly and testing costs. Second, the fusion of functions into a single, solid state component that previously required multiple, interacting modules reduces the complexity and increases the reliability of space systems. This lowers engineering, assembly and tests costs, allows greater modularity of design, shortens development time and facilitates the mass producibility necessary for building a constellation of satellites. In combination with the greater autonomy of the spacecraft which is made possible by increased onboard computing power, less complex spacecraft require a lower level of expertise to operate which broadens the

range of users who can exploit the benefits of space.

19. Space communications is an application of space technology which requires improved responses to the needs of the end user. Systems have been designed which could offer affordable, hand portable, worldwide mobile satellite communications. In order to reduce the size and power of the handset, such systems require multiple satellites orbiting closer to the Earth than do traditional geosynchronous communications satellites. To make such a capacity financially feasible, the spacecraft must be inexpensive and designed so that several can be launched at the same time on a reasonably priced expendable launch vehicle. Additionally, it must be possible to replace an individual spacecraft if it fails. Traditional, large spacecraft and launchers cannot meet all of these requirements.

20. The complexity of a satellite system is a function of the complexity of the individual satellite and the number of satellites required for the full constellation. The complexity of a communications satellite is generally an inverse function of the orbit altitude, that is, the higher the orbit, the more complex the satellite. This is because the size of the spot beam on the Earth's surface is driven by the power of the handset which must be less than 50 miliwatts in order to comply with biological hazard requirements and the need to re-use frequencies among as many small spots as possible in order to reduce the total spectrum demand. Hence, the higher the orbit, the larger the diameter of the satellite's antenna and the more complex transponder required to achieve traffic routing flexibility. On the other hand, the higher the orbit, the fewer satellites that are required for a communications system. This was one of the key factors that led to widespread use of the geostationary orbit for communications applications.

21. Technological developments in the 1980s and early 1990s, particularly in miniaturization, has enabled dramatic improvements in the capabilities possible with small space systems. Perhaps the most substantial benefit of miniaturization is that it reduces launch costs. The launch segment typically accounts for half of all mission expenditures and successful miniaturization and consequent reduction in weight of electronic, optical and structural components has significantly improved the performance-to-weight and performance-to-volume ratios of most mission payloads, spacecraft bus, launch vehicle and ground sub-systems.

I. TECHNICAL, ECONOMIC AND REGULATORY ASPECTS OF LEO SYSTEMS

22. Any communications system which can provide customers with the means to communicate from any place, at any time and at over any distance necessarily provides certain social and economic advantages. This capability does not presently exist in many parts of the world. Assuming that it did, however, the primary limitation on such a system would be the availability of the person called. The called party may not be close to his telephone when he or she is called and the failure of urgent communications (to police, fire authorities, hospitals, etc.) to be connected because there is no reply at one end of the link could have dramatic consequences if there is a delayed response or if the call remains unanswered. It is therefore essential to provide the person with a means to communicate.

23. The growth of terrestrial cellular networks that provide telephone services to hand-held and vehicle-mounted terminals are presently restricted by urban and suburban boundaries. Geostationary satellite systems with only three or four spacecraft in orbit can provide service to almost the entire populated world. However, they also require more than one hundred very narrow beams (produced by very large apertures), complex transponders and large amounts of power to provide personal communications. They cannot provide coverage at far northern and southern latitudes and for latitudes greater than 80°, a geostationary satellite is just below the local horizon. Moreover, because of the propagation anomalies close to the local horizon, even for the fixed terrestrial stations with large antennae it is often difficult to operate lower than 5°-7° above the horizon. This results in operational latitudes on the Earth which are narrowed down to around 75°. In the case of hand-held terminals, they must be equipped with an omnidirectional antenna which typically requires

a much higher angle of elevation, around 20°-30°. The situation for urban areas is even worse because of tall buildings which can block signals.

24. The selection of an appropriate constellation for a LEO system is a complex interaction between the need to optimize the service area and the need to minimize the number of satellites in the constellation. In addition, the performance of the launcher to be used and the potential impact of a satellite failure must be considered during the development phase of a project. Because there will be long periods during which the satellites will be out of view of the control station, each satellite must have considerable autonomy to perform traffic management and recording functions. Non-routine changes such as system configuration changes, routing and networking functions and overall system management would be handled by the central control station

25. Selecting the orbit for the satellite constellation must take the following parameters into account:

- degree and homogeneity of Earth coverage;
- traffic projections for system operational lifetime;
- hand-set power with omnidirectional antenna;
- terrestrial view angles;
- signal propagation delay;
- antenna size and electrical power of the spacecraft;
- spacecraft autonomy;
- satellite lifetime considering its exposure to the Earth radiation belts and atmospheric drag;
- cost of the space segment deployment and maintenance, including that of launches; and
- overall system reliability.

26. The selection of orbit altitude is also related to the question of what type of satellite constellation is necessary to provide global coverage without gaps. Higher orbits require fewer satellites but there are other factors involved in orbit selection. First, some orbit altitudes are undesirable because of the high level of trapped radiation in the Earth's two radiation belts. It is necessary to stay below both these belts, between them, or above them. This narrows the choice of orbits to ranges of altitudes below 1,500 km to stay below the radiation belts, between 8,000-12,000 km for a constellation to be between them, or 20,000 km to be above them.

27. The selection of orbital inclination is also related to the choice of orbital altitude. Higher orbital altitudes permit coverage to a given latitude at lower angles of inclination. The number of planes necessary for full coverage is determined by equatorial coverage and the number of satellites in each plane follows from that choice. At any particular location on the Earth. the number of visible satellites will depend on the latitude. Having a large number of satellites provides better connectivity. Closer to the Earth's poles, where the need for services approaches a minimum, a greater number of satellites are nevertheless visible.

28. Highly elliptical orbits provide high angles of elevation even in the polar regions for satellites which spend most of their 12-hour orbital period near apogee over the northern hemisphere. This represents a good solution for providing regional coverage because satellites stay over a given region for long periods. These orbits typically have apogees around 40,000 km and perigees of less than 1,000 km and are inclined to the equator at the unique angle of 63.4°. This angle is a peculiarity in orbital mechanics that causes the major axis of an elliptical orbit, inclined to the equator at that angle, to remain in a fixed orientation despite the effects of the Earth's gravitational field non-isotropy which would normally cause that axis to rotate and the apogee to drift towards the southern hemisphere of the Earth.

29. An operating system using the above orbits would require two planes with two satellites in each, having a rotational period synchronized to half of the Earth's rotational period. To maintain 24-hour

coverage, terrestrial receiving stations should slowly track and hand-over the signal from one satellite to another. A paramount drawback for this type of orbit is that each satellite in the constellation will pass through the Earth's radiation belts twice during each revolution. The exposure of spacecraft electronics to this high level of radiation ultimately damages the spacecraft. Regardless of electronics hardening measures, this process will eventually decrease the lifespan of the satellite. Because of this, several variations of this type of orbit have been found with a perigee above the Earth's radiation belts.

30. The optimum candidates for LEO systems are polar orbiting constellations with an equal number of spacecraft equidistantly distributed in each orbital plane. The satellite orbits will be circular. The preference in this type of system would be for polar orbits below 1,000 km altitude so that the effects of radiation are minimized. If an altitude equal to 780 km is selected, the coverage area of the satellite would be a circular area with a 5,00 km diameter. This surface coverage area moves along the satellite subtrack. Due to the Earths rotation, the satellite's subtracks shift about 25° west from one orbit to the next. For this reason, a multi-satellite constellation is required to provide service with acceptable discontinuities.

31. Uplinks and downlinks can be described as functions of the spacecraft, user terminal features, and the parameters of the satellite constellation. The rate of information transmission determines the bandwidth needed per channel and, together with the communication traffic to be carried, defines the total spectrum required. Because of the demand for shares of the electromagnetic spectrum by competing services and especially the demand for the desirable frequencies between 100 MHz and 3 GHz, it is just about impossible to get enough spectrum for a satisfactory system without reusing the same frequencies. The practical consequence of this regulatory situation is that it will be necessary to make the terrestrial spot much smaller than that of the geometrically visible area. Therefore a cellular pattern in which the channel frequencies can be reused several times must be built into the system. The higher the orbital altitude, the larger the spacecraft antenna must be to achieve the fixed spot size on the Earth's surface. The size of the antenna will therefore be defined by the size of the smallest coverage cell in the terrestrial mosaic.

32. The integration of data and voice transmission leads to the logical issue of digitized voice technologies. In recent years, the capacity of digital signal processors (DSPs) and memory systems has increased by more than 1,000 per cent. It is this breakthrough in DSP technology that has allowed various voice coding techniques to become a viable proposition. Apart from providing a common base, digital systems can also provide improved audio quality in many portions of an RF spectrum. Because of interference and fading, the quality of analog voice transmission varies over the range of its transmission. This is different when dealing with digital technologies. About 15 years ago, due to advances in the electronics industry that made possible the mass production of integrated circuits, digital voice transmission came into wide use in telephone networks. Coupled with time-division switching, it has enabled fully digital networks to be built, including integrated service networks for audio transmission. With digital voice transmission technologies, it is now possible to include error correction information. With this information the receiving terminal can recognize and correct errors in the digital bit stream.

33. Digital communication techniques are the most promising schemes not only for efficiently utilizing the limited spectrum but also for minimizing power requirements for satellite and/or mobile terminals. For digital transmission systems the modulation spectral efficiency is determined by the number of bits per second that can be transmitted in each Hertz of spectrum. Efficiency of frequency reuse must also be considered in determining overall spectral efficiency. A frequency channel can be used in two (or more) areas if sufficient isolation between the areas can be obtained by physical separation, antenna patterns, or other propagation factors. In the future, therefore, mobile satellite communication systems will be designed based on digital communication techniques which include digital modulation, forward error correction and voice coding. The most important technical development is the transition from analog to digital mobile terminals. By converting the human voice to computer code, at least 1,000 per cent more calls can be sent over the same range of the radio spectrum. That should relieve service problems in large cities where too many

cellular subscribers are often trying to get onto the airwaves at the same time. In several European countries where a continent-wide common standard has been adopted, digital cellular systems are already operating. But in the United States a dispute over two proposed digital technologies has delayed this transition.

34. So-called multiple access methods have been developed to minimize the use of a single RF channel. They are: Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA).

35. The traditional technology for multiple access is FDMA. With FDMA, the spectrum is divided into a large number of channels. A separate channel is required for each call with the desired signal separated from signals on other channels by the use of bandpass filters. FDMA effectively splits a single 25 KHz channel into two 12.5 KHz digital channels. FDMA is a frequency independent band and can be used anywhere that 12.5 KHz channels can be used. FDMA utilizes narrow band transmission and reception similar to that of conventional communication systems. However, unlike normal communications which are fixed in frequency, roaming FDMA looks at the frequency band to check for frequency occupancy before transmitting. If a frequency segment is in use, it will keep searching the spectrum until it finds a vacant slot before transmitting. Roaming FDMA services will suffer from degraded performance when a LEO satellite does not detect interference and transmits on a frequency on which there are interference problems. An example of this could be from services transmitting with a very low angle of elevation. Additionally, roaming FDMA will have degraded availability if there are no spare frequency slots to be utilized due to many terrestrial transmissions being detected by a LEO satellite.

36. With TDMA technology, a frequency channel is divided into a number of orthogonal time slots. A different time slot is used by each individual signal. A desired signal is separated from other signals by the use of a time gate. Data transmissions must be accelerated while the transmitter is on to make up for the time when the transmitter is gated off. Therefore, TDMA uses a different approach to maximize throughput on a 25 KHz RF channel. In fact, it divides the channel into repeating split-second time slots and then sends digitized calls in short bursts. But the time divisions are so close together that callers do not notice any delay. This technology is now available for use and could, if utilized, increase cellular capacity up to 600 per cent. In the case of TDMA each satellite station shares a transponder by transmitting short synchronized non-overlapping (at the transponder) bursts. Receiving stations receive all bursts from the transponder concerned and only extract those bursts addressed to them for subsequent baseband processing. Thus, only one carrier is ever present at the satellite transponder. TDMA is suited to highly interconnected networks with very variable station-to-station traffic capacity. The re-allocation of capacity is simply performed by re-allocation of burst length rather than by changing filters and frequency synthesizers as in FDMA systems. TDMA is frequently combined with FDMA by first dividing the allocated spectrum into a number of frequency channels. Each of the frequency channels is then divided into a number of TDMA time slots.

37. Just when the cellular industry decided to utilize TDMA technology, however, the very promising CDMA technology became available. CDMA promises to expand capacity by at least 1,000 per cent. The technology is also sometimes referred to as spread spectrum technology. It is essentially a different approach to frequency or time division multiplexing techniques in that it actually spreads its transmitted energy over a very large amount of spectrum providing a low powered signal which is resists interference due to its coding. CDMA breaks a digitized call into segments called packets and then assigns a code to each packet. These packets are intermixed with packets from other calls and dispatched over many radio frequencies. Because of the coding technique involved, each radio can determine which messages are meant to be received. The calls are actually reassembled according to their code.

38. Thus, with CDMA technology, each signal is modulated onto a wide bandwidth spread spectrum carrier that is produced by phase modulation of a sinusoid by a pseudorandom-noise (PN) binary sequence of digital signaling elements, called "chips". The bandwidth of a single signal is much wider than would be

required for the same data transmission rate using FDMA technology. It may seem paradoxical that the latest prescription for most efficient use of the spectrum essentially goes against previous techniques that sought to minimize the among of spectrum being used and instead seeks to use as much of the spectrum as possible. However, this technique allows a statistical averaging principle known as the "Law of Large Numbers" to come into effect with the result that the system more efficiently re-uses frequencies than either FDMA or TDMA technologies.

39. Each signal uses a different PN sequence. A desired signal is separated from other signals by use of a correlator in the receiver which is matched only to the desired signal's PN sequence. The signals look like random thermal noise, and are about 10 dB weaker than the thermal noise in the receivers. The correlator provides "processing gain" to increase the carrier-to-interference (C/I) ratio by the ratio of the spread spectrum bandwidth to the system's data rate.

40. With FDMA and TDMA technologies, frequency re-use is limited by the necessity to attain an adequate C/I ratio. Typically, one or only a few other signals will be sharing a frequency channel with the desired signal. These signals can be present in the same frequency and time slots (co-channels) as the desired signal, frustrating the effort to maintain signal orthogonality. Propagation conditions and other transmission variables require that worst case conditions be used to determine the necessary degree of isolation between co-channel users. In cellular systems, a frequency re-use of about one in seven is required for adequate performance. This means that a frequency used in a given cell will not be re-used in any neighbouring cell (or in that of a neighbour's neighbour).

41. With CDMA technology, a large number of signals are co-channel users of a wide-bandwidth frequency channel. Each signal generates noise in the receivers of the other signals. The C/I ratio is determined by the ratio of the desired signal to the sum of all of the co-channel signals and thermal noise. If the system is designed so that there are a large number of co-channel signals then no single signal interferes with the others. Instead, the average of all the interferers' signal power determines the C/I ratio for each signal. This means that "worst case" analysis is not applicable. The wide-band channel is used in every cell, thus avoiding the one in seven re-use inefficiency of FDMA and TDMA. The result is an increase in spectral efficiency.

42. Spread spectrum technology has been used for military communications systems for many years but the performance characteristics of specific systems were generally classified. In a qualitative sense the comparison between CDMA and FDMA for a satellite system is based on three practical limitations: bandwidth, satellite antenna and satellite RF power. The literature contains the following conclusions regarding a comparison between CDMA and FDMA technologies: a) CDMA is less sensitive to Doppler shift than FDMA; b) CDMA is less sensitive to precise timing than TDMA; c) ranging measurements are easily "built-in"to CDMA; d) coding can be implemented without increasing bandwidth; e) the voice activity factor is easier to utilize; and f) broadband spreading offers resistance to fading

43. CDMA confers a number of advantages that in turn translate into a more efficient system design. It permits a greater degree of frequency range than other approaches as often as once per beam. This in turn permits "soft hand-offs"from beam to beam and satellite to satellite that do not require any adjustment at the user terminal. CDMA systems also have a "soft"capacity limit that automatically adapts to changes in systems characteristics. This means that the addition of a user above the nominal capacity limit slightly degrades the signals of all users sharing the spectrum rather than catastrophically degrading the signals of a few others.

44. CDMA techniques do not require complex switching electronics in order to implement voice activation, an important means of increasing capacity. Spread signals have better resistance to multipath fading and naturally permit high geolocation resolution. Finally, the power control required by efficient

CDMA systems and modern electronic techniques are providing modern techniques for meeting the precise CDMA synchronization requirements. However, CDMA will suffer from reduced performance when a large number of CDMA users appear concurrently on a given part of the spectrum. As more and more users utilize the service, the radio frequency band noise will increase and the link margin will decrease accordingly.

45. In normal speech, there are pauses where nothing is said. The time of this pause varies with the speaker, but a good value for this "voice activity factor" is about 0.4. That is to say that, on average, 40 per cent of the time someone is speaking and they are silent 60 per cent of the time for any given conversation. This is an average, and represents very short pauses such as those between words in normal conversation. In an FDMA system, it is very difficult to take advantage of this fact, because if the channel is assigned, the power can be turned on and off to track the voice (voice activation) but the channel cannot be reassigned for that period of time. Voice activation thus can help reduce the average power required, but does not increase the maximum capacity.

46. In a CDMA system, both power reduction and capacity increases are achieved automatically. By employing voice activation, when there is a pause in speech, that transmitter power is not used, just as with FDMA. Since it is not used, however, the background voice level is lowered by the same amount for all other users. Since the "voice activity factor" is an average over time and a population of users, it fits naturally into a CDMA system. If the calculations show that N continuous users can be accommodated, with voice activation, 2.5N simultaneous calls can be accommodated at the same performance levels, since the averages dictate that the users are talking only 40 per cent of the time.

47. A common characteristic of the so-called "Big" LEO mobile satellite systems is that for feeder links they all need spectrum in the frequency range of 1 GHZ to 3 GHz which is very limited even after the decisions at WARC-92. By their very nature, these systems are worldwide in the same way that many geostationary systems are.

48. The problem of potential interference are of paramount importance. Satellites of any given LEO system will interfere with the earth stations of another system as well as with those of existing terrestrial systems. The present design philosophy for satellite communications systems utilizes the fixed on-station positions of the geostationary satellite and directional antenna pattern of the earth station while covering the same geographical area. LEO systems for mobile and broadcast services do not have these features. Non-geostationary satellites will pass along the boresight of an earth station antenna of a geostationary satellite network. This could cause interference to both the satellite and earth stations. Often interference at either a satellite or at an earth station will be the sum of the interference from several satellites in view at any instant.

49. The LEO systems currently under consideration can be divided into two categories: those that will use FDMA/TDMA techniques and those that will use FDMA/CDMA techniques for user links (so called L-band and S-band). The two categories of systems cannot share the same band because doing so would affect the system's capacity to handle traffic. Moreover, the same frequency band (L-band) is also used by other services such as radio astronomy, navigational satellites and others. This will require coordination with several countries. The possibility of the satellite operating in different frequencies at various parts of its orbit will adversely affect its weight and reliability.

50. Communications via such personal mobile satellite communications systems are established by connecting the satellites to the end-users, and, if necessary, through the existing terrestrial networks. The systems proposed vary in their technical parameters and the estimated costs of these systems range from $500 million to $3.5 billion. These costs are mainly for the construction and launching of the satellite constellations which range from 12 to 66 satellites for systems which do not utilize the geostationary orbit. Fewer satellites may be required for systems utilizing the geostationary orbit. The hand-sets are likely to cost

anywhere from a few hundred dollars (comparable with existing cellular receivers) to $3,500 for the most sophisticated handset envisaged. Consequently, preliminary estimates of the final price to users for calls on these systems also vary considerably, from $.33 to $3.

51. The following are brief descriptions of the principal proposals for the so-called "Big" LEO systems. The principal technical parameters of these systems are summarized in the table at the end of the survey.

II. LEO SYSTEMS UNDER DEVELOPMENT

A. Iridium

52. The Iridium system is envisioned as a digital communications system that will operate in a cellular communication architecture. The constellation of LEO satellites will cover the Earth with beams turned on and off as necessary to ensure coverage of the entire planet. However, LEO orbits will require the satellites to be lower relative to the Earth's surface, so a large number will be needed to ensure that all areas are continuously covered. The emphasis in the Iridium programme is on the personal communication device, the hand-set, which will be small enough to carry in a pocket, will run on rechargeable batteries and be able to operate in environments typical of today's cellular telephones. The Iridium system will be composed of four functional components: the space segment, the system control segment, the gateway segment and the end-user unit segment.

53. The space segment will consists of a constellation of 66 small (approximately 700 kg) satellites in LEO. This constellation is comprised of six polar-orbital planes with each plane containing 11 operational satellites which orbit the Earth at an altitude of 780 km with orbital periods of 100 minutes. This orbit is low enough to avoid radiation problems in the Earth's radiation belts and high enough to avoid atmospheric drag, which would require higher power consumption and cause more wear on the satellite.

54. The end-user unit segment will provide the means by which the subscriber communicates via the Iridium system. The user products will include hand-held and mobile telephone (single and dual mode), solar-powered phone booths, specialized aeronautical and marine units and a variety of paging products. Each user product will provide one or more of the system user services which include voice, data, facsimile and position locations.

55. The goal of providing high quality, reliable voice communications from a hand-held unit has been the focal point of the system design and development effort. Proprietary empirical tests, conducted by Iridium's designers in conjunction with some of the world's leading authorities on propagation phenomena have shown that quality voice communications require more link margin than originally envisioned. The system's original baseline design envisaged 6 dB-12 dB link margin, however, results from field tests showed that approximately 16 dB of link margin is required in the cluttered environments typical of a large segment of Iridium's projected user base. This contrasts with CDMA-based systems which are characterized by a capacity similar to Iridium's but which are based upon low link margins (less than 4 dB).

56. Iridium is an upside-down cellular system. In traditional cellular networks, the infrastructure is on the ground, the cells are fixed and the user moves through them. With Iridium, the infrastructure is in space, the cells rotate across the Earth as the planet spins, and the user can be regarded as stationary, relative to the speed of satellites. So this is not a space system in the traditional sense but rather is a communications system that happens to have some of its infrastructure located in space.

57. The Iridium user could call any telephone number on the Earth and be connected almost instantly to the appropriate land line, mobile cellular phone or another Iridium phone. Placing a call to an Iridium phone would require only that the caller know the number assigned to that unit. The system would be able to locate

it quickly because when that phone is turned on, its location is automatically registered with the user's home gateway, where all the billing is handled. The Iridium system is not a substitute for existing telephone or cellular systems, which by their nature have much more capacity and lower rates. It is also not a service that will bypass local, national or international regulatory issues. The system uses a combination of FDMA and TDMA signalling techniques to re-use frequencies in a seven cell pattern.

58. The satellites will be networked together through inter-satellite links forming an interlocking, seamless web. Each satellite will utilize state-of-the-art phased array antennae to generate 48 separate spot beams to form cells on the surface of Earth. Iridium will employ communication links in two portions of the spectrum. The up/down links between the satellites and the user are being designed for L-band operations. The satellite's crosslinks, as well as the up/down links to the gateway stations, are being designed for Ka-band operations.

59. The 48 beams of the satellite are being designed for independent operation and each will employ a different amount of power to close the links. The beam pattern will be fixed relative to the spacecraft bus, but rapidly moving on the Earth's surface. Handoffs will occur from beam to beam as a user unit is operated, similar to today's cellular telephones, but unlike those cellular telephones, the Iridium beams will move through the user, rather than the users moving through the cells. Handoffs will occur with the same frequency, about one per minute, as with cellular telephones, but the handoffs in Iridium will involve fewer handoff options and better information to choose from among the options than today's cellular telephone systems. In that sense Iridium will be less complex. However, since Iridium's beam patterns overlap little in low latitudes and very much in the high latitudes, Iridium must overcome two problems that do not exist with cellular telephones: a) beams must be switched on/off depending upon their position in the orbit. When at the equator, an individual beam will be on, and at some high latitudes in each orbit it will be switched off for a period of time meaning that at any given time approximately 2,150 (60 per cent) of the system's 3,168 cells are on. Of course, if operations are prohibited in some part of the world, more cells may be switched off; and b) the pattern of channel re-use must be reset at different times during an orbital period.

60. The re-use assignments will employ a combination of fixed and dynamically assigned channels, so that the needs of the entire world, as well as isolated localities, can be efficiently balanced.

61. Where an area is covered by a terrestrial-based cellular system, Iridium will be a back-up or emergency service. In areas of the world where no mobile service is readily available, Iridium will be the mobile system. In areas of the world where mobile service is only provided with geostationary satellites, Iridium will provide more channels, shorter delays, and worldwide networking capabilities. And, in areas of the world where there is no telephone service, Iridium will perform that basic function.

62. Iridium customers will be widespread and varied. An international business person with a portable subscriber unit in his coat pocket will have access to his or her home office, and the head of a large multinational corporation can quickly contact any of his or her general managers, whether they are at home or travelling anywhere in the world. Developing countries without a telephone infrastructure can have a subsidized, solar-powered, centrally-located telephone booth in every village. Land and sea mining operations can have continuous worldwide service. And, areas experiencing natural disasters can maintain reliable communications with the rest of the world.

B. Globalstar

63. Globalstar will deploy a constellation of 48 LEO satellites in circular orbits with an altitude of 1,406 km in eight orbital planes, each with six satellites equally spaced within the orbital plane to provide continuous coverage of the Earth. Each orbital plane will have an inclination angle of 52° degrees. Each satellite will have a 7.5° phase shift to the satellite in the adjacent plane. Each satellite will operate as a

simple frequency translating repeater in space, eliminating complex set-up procedures and the need for on-board processing capabilities. The system is being configured so a mobile user will be linked to a terrestrial gateway directly through individual satellites, thereby eliminating the need for satellite traffic crosslinks.

64. The six spot beams of the satellite will generate elliptical coverage cells on the surface of the Earth. The major axis of these elliptical coverage cells will be aligned with the velocity vector of the satellite's movement. Therefore, the time a user stays within the same satellite beam "cell" will be increased and the number of call hand-off operations among the satellite beam "cells" will be decreased. The Globalstar satellites spot beam antennae are also being designed to compensate for the difference in the satellite-to-user link loss that can occur between the "near" and "far" users, so that the power flux density of the "far" users will be the same as that of the "near" users. This Globalstar antenna design will eliminate the "near/far"problem experienced by many cellular-type systems.

65. Each satellite will communicate with the mobile user via satellite-user links and with gateway stations directly via feeder link. Each gateway station will communicate with three satellites simultaneously. The gateway station will handle the interface between the Globalstar network and the PSTN. This equipment will be supplied by gateway owners/service providers. There will be many gateway stations distributed throughout the world. Gateways will be configured to match the capacity requirements of given service zones to minimize costs. A particular influence is the scope of existing PSTNs. Each country can independently have its own gateway or gateways and control access to the system by users within its own boundaries. The system will include instant position location capabilities to establish user location for each call, either inbound or outbound.

66. The Network Control Centre (NCC) will provide the capability to manage the Globalstar communications network. Its functions will include registration, verification, billing, network data base distribution, network resource allocation (channels, bandwidth, satellites, etc.) and other network management functions. Other Globalstar services, such as message services, will also be provided through the NCC. The Constellation Control Operation will include the Tracking, Telemetry and Command (TT&C) station and the Spacecraft Control Operation Centre (SOCC). The TT&C stations will monitor each satellite's operation by the telemetry of the satellites and send commands to the satellite to control its on-orbit performance. The TT&C station will also perform tracking and ranging functions for the orbiting satellites. The SOCC will process the satellite's orbit information for various network functions. It will plan and execute orbit station-keeping for the satellites so that all satellites are maintained in the appropriate orbits.

67. During the initial phase of the Globalstar network, there will be two kinds of user equipment. These will be based on small, omnidirectional antennae and include hand-held terminal units for voice and radiodetermination satellite services (RDSS) and vehicle-mounted and fixed units for RDSS-only terminals. As market demand rises, other user equipment, providing various Globalstar RDSS, voice, and data services will also be introduced.

68. The Globalstar system will provide voice and data services in conjunction with terrestrial cellular telephone service providers and/or other communications services providers. The Globalstar system will serve three main user groups: a) fixed users working in and/or resident in areas with terrestrial mobile coverage; b) fixed users working in and/or resident areas without telecommunications service; and c) private or specialized network operators.

69. User groups might include government agencies, commercial entities such as fleet managers, land and water vehicles and transportation providers, business travellers, and emergency services providers. Government agencies will benefit from two-way voice communications and position location capabilities in the areas of disaster relief, law enforcement, air traffic control, resource management and weather reporting. Commercial users might use the Globalstar system for connections with rural facilities that are not served by

PSTN or cellular networks. Utilities that require regular but infrequent monitoring, security services, and resource management systems are also potential users. Fleet management entities such as interstate trucking firms, passenger bus operators, rail freight and inland waterway line are also potential users.

70. The Globalstar network architecture has been designed to support many quality voice and data services in an efficient manner. Although all gateway stations will link users to existing networks, some Network Coordination Gateways (NCGs) will perform the more complex functions of the operations centre of a Globalstar service provider. An NCG will have additional equipment to perform resource assignments, network timing and coordination, and communications load monitoring. All of a service provider's standard gateways will interface with the NCG through a packet-switched data network.

71. Billing will be based on circuit time usage and type of service. Voice calls will be charged from the time a call is answered until the circuit is released. Data service charges will be based on the amount of bits transmitted, which is equivalent to the amount of time network interfaces are used.

72. The system has enough flexibility and expansion capability to meet increasing demand. The satellites are being designed to have a lifespan of 7 1/2 years. Using a simple satellite design and overlapping coverage, continuous and reliable service will be provided to Globalstar system customers throughout the life of the first generation of the system. Additional satellites can be launched to provide greater satellite coverage over all areas. The Globalstar system's use of CDMA will allows the capacity in areas covered by two or more satellites to increase significantly. Increasing the number of satellites within a range of a mobile terminal doubles the satellite's power flux density which nearly doubles the capacity in the area of two-satellite coverage.

C. Ellipso

73. Ellipso is conceived as a system that will be able to extend telecommunications services throughout the world to users that are not served at all or are inadequately served by existing mobile and fixed telephone systems. To do so, the Ellipso concept features LEO satellites and an efficient system design to reach its subscribers directly and at a price that will be competitive with terrestrial telephone services, around $.50 per minute. Ellipso will not only offer the user mobile telephone services, but also other digital services, such as data transfer, facsimile, paging, voice mail, and messaging. This system will not bypass existing telephone system in offering these services but rather will extend them.

74. Developing a viable and flexible business plan remains the most important element of the design of the Ellipso system. The market potential for mobile satellite services remains tentative. Therefore Ellipso will be capable of offering a profitable, economical service to a conservatively sized market in order to succeed and grow while hedging market risks. Furthermore, the design of the Ellipso system contains built-in flexibility for tailoring its geographic coverage to potential market success.

75. The Ellipso system will profitably operate serving a conservative market size of only 250,000 subscribers anywhere in its coverage area. It's constellation of LEO satellites will assure not only even coverage around the Earth for each latitude, but also coverage over the entire populated Earth that is tailored to the Earth's population latitude. The developers of the system have estimated that approximately 600,000 users will subscribe to Ellipso worldwide.

76. The Ellipso system will be unique in that it will splits its global coverage into two zones roughly divided by the Tropic of Cancer. The system deployment schedule and capacity for each zone can be adjusted to optimize global coverage to investment and demand as necessary. Northern coverage is provided by a northern part of the system, using up to 18 satellites in 63.4° degree inclined elliptical orbits in several planes with northern apogees at 2,903 km and perigees at 426 km. These elliptical orbits have been selected

in order to concentrate most of the deployed satellites north of the equator at any one time, where they will be able to provide service for a greater percentage of their orbits than if the orbits were circular. Additional orbits and satellites in the constellation will extend coverage to tropical and southern latitudes.

77. Ellipso will use simple transponder satellites. For most markets the system will divide the 16.5 MGz mobile uplink and downlink spectra into multiple frequency segments, each carrying a number of user signals to and from the mobile terminals. But an important advantage of the transponder approach to satellite design is its flexibility to accommodate any changes in modulation or multiple access techniques. Such changes may be called for to implement future system improvements or to tailor Ellipso to the specific technical characteristics of each region's infrastructure.

78. The Ellipso satellite will be simple and light, around 200 kg. The communications payload will primarily consist of frequency shifting transponders and the appropriate antennae for forming the needed beams on the Earth. Proven components and spacecraft designs will be used to the maximum extent possible. Electronic processing functions will be performed in the terrestrial stations to reduce satellite costs and allow the flexible processing approach according to regional needs as discussed above. Ellipso will use CDMA signalling techniques to permit multiple users to share spectrum simultaneously.

79. Ellipso satellites may be launched up to six at a time while the constellation is put in place. Replenishment of the constellation will require the use of small boosters to launch one or two satellites at one time. The first twelve satellites will be adequate to initiate northern hemisphere service, although some small outages in service may occur occasionally at lower temperate latitudes. An additional six satellites in complementary orbits will provide complete and continuous northern coverage and initiate continuous coverage of the tropical and southern latitudes. The final six Ellipso satellites will add capacity to those regions of the globe having additional demand, and can be deployed in any of several combinations, depending on the distribution of demand.

80. The Ellipso user terminal will be comparable in form to those used for cellular telephony. In fact, Ellipso is being designed to facilitate seamless switchovers from terrestrial cellular systems to Ellipso communications when cellular systems becomes unavailable to the user. Ellipso's signal parameters were selected to correspond closely to anticipated future terrestrial CDMA cellular designs. Necessary upgrades to add Ellipso service capabilities to terrestrial cellular terminals of any type will be held to a minimum. Ellipso user terminals should cost around $1,000 within one to two years after the system becomes operational.

81. Regional Ellipso ground control stations and network control centres will interconnect the satellite links to terrestrial networks and manage resources and customer records for Ellipso. As necessary, various Ellipso band segments can be assigned to different terrestrial administrations in order to maintain overall national or regional communications system integrity.

D. Odyssey

82. The Odyssey satellite communications system is intended to provide high quality wireless communication services from satellites. These services will include: voice and data transmission, paging and messaging. Odyssey has been designed using an economical approach to providing communications. To provide continuous coverage of designated regions, a constellation of only 12 satellites will be orbited in three 55° inclined planes at an altitude of 10,354 km. Such a constellation will provide continuous global coverage with dual satellite visibility in some major regions of the world. This dual visibility will result in high line-of-sight elevation angles. Odyssey satellites are being designed with full redundancy for 10 years of on-orbit lifetime to reduce the cost of ownership.

83. The medium Earth orbit (MEO) chosen for the Odyssey system has several other advantages, including: a) the propagation time delay will be reduced to only 68-83 milliseconds which is imperceptible to human ear; b) the satellites will be in orbital positions between the Earth's inner and external radiation belts, which will reduce the radiation shielding required on the satellites and will enable them to survive in this environment for the same 10-year period which is typical of LEO satellites; and c) only nine satellites will be required to ensure that one satellite is visible at all times, thereby allowing continuous service to several regions to be initiated with those satellites and only requiring the addition of two or three more satellites for service to be available to all regions of the world.

84. This system will provide a link between mobile subscribers and PSTNs via dedicated ground stations. Although the maximum propagation delay is 84 milliseconds from an altitude of 10,534 km, and a PSTN network can add up to 20 milliseconds, the total delay is still almost imperceptible to the user. The satellite will illuminate its assigned region with a 10-beam, 5° beamwidth multibeam arrangement. Terrestrial toll networks will be used for intercontinental calls.

85. The design of the Odyssey communication system is being driven by several key requirements of personal telephone users, particularly those related to the central component of the system, the hand-held personal telephone. These key requirements therefore include:

- full duplex voice communication;
- high quality voice encoding;
- 24-hour system availability;
- communication capability covering all of the global land masses;
- low-cost hand-held personal telephones (HPTs);
- dual mode compatibility with terrestrial cellular systems;
- battery capacity for 24 hour standby mode;
- hand-held personal telephone operation similar to terrestrial cellular;
- alphanumeric paging capability;
- meet health and safety standards; and
- data transmission capability.

86. The gateway station shall provide the connection between the Odyssey satellite link and the PSTN in each region. Most cells will be directed to the local PSTN. Long distance calls will be directed to the designated long distance PSTN in the gateway region. The rare Odyssey-to-Odyssey calls will be routed to the appropriate gateway station through dedicated inter-gateway leased links. The gateway station will also provide all signal processing for the Odyssey system. Each station will be equipped with four 3.3 m tracking antennae spaced 30 km apart. Three of the antennae may be simultaneously communicating with many satellites. The fourth antenna will be available to acquire an additional satellite, so that handover of responsibility from one satellite to another can take place without a gap in communications. The fourth antenna will also perform diverse functions in the event of heavy rainfall, since rain-producing storm clouds are typically much less than 30 km in diametre.

87. For the call setup with the Odyssey system, priority will be given to the use of the terrestrial cellular services. When a call is placed, the hand-held personal telephone will first sense the presence or absence of cellular frequencies and attempts to place a call through a local cellular network. If cellular service is not available or the call is blocked, then the call will be routed through the Odyssey system. User circuits established through a particular satellite enter the PTSN at a ground station located within the region served by the satellite.

88. All communication processing will be performed on the ground which will allow the use of a simpler satellite payload design. The transparent or "bent pipe" transponder will also have the advantage of allowing

different communication formats to be routed through the satellite to accommodate various regional demands. The transparent design will also give the Odyssey system the capability to be compatible with future communication formats. The Odyssey system will use the CDMA signalling method.

89. Many studies have been conducted to define the service areas to be covered by the Odyssey system. At any time most of the satellites will provide primary service to these defined regions. Additional satellites will be used for the transition before a satellite moves on to the next assigned region. Traffic will build up on the approaching satellite while it wanes on the satellite leaving the service area.

90. Perhaps the most important advantage of the Odyssey system will be its high view angles. Two Odyssey satellites will be visible anywhere in the world at all times. This dual coverage will result in high line-of-sight elevation angles, thereby minimizing obstructions by terrain, trees and buildings. The MEO utilized by the system will provide average view angles in the range of 45-55° at all latitudes. With the full constellation, a minimum line-of-sight elevation angle of 30° (depending on the user's latitude) will be guaranteed to at least one satellite more than 95 per cent of the time. This will be a major benefit to the user because obstructions from trees, buildings and terrain can be avoided and less link margin will be required in the communication link budget.

91. The estimated cost of the Odyssey service is $0.65 per minute with a subscriber base of two million users. The system would provide high priority service for premium customers who require reliable mobile communications via a small hand-held terminal. Subscribers can have a single telephone which roves with them and does not require special access codes. It is believed that users of the Odyssey will include private and governmental institutions/agencies which have a compelling need for continuous service over wide regions, business travellers, residents of sparsely populated regions who will never receive cellular service because there are not enough subscribers to pay for their infrastructure, and citizens of nations which lack adequate communications infrastructure.

E. Project-21

92. INMARSAT's personal communications strategy, known as Project-21, represents the evolution of personal mobile satellite services, which the organization has been introducing throughout the 1990s. Project-21 has four primary components:

a) INMARSAT-C, for portable mobile data transmission (in service since 1991);
b) INMARSAT-M, a briefcase telephone (in service since 1992);
c) Satellite paging to pocket receivers (to be introduced in 1994); and
d) INMARSAT-P, a global hand-held satellite phone, (to be introduced by 1999).

93. The basic objective of the INMARSAT-P service is to provide telephony to and from hand-held terminals with an unobstructed satellite view and with a voice quality similar to that of digital cellular systems. The design of INMARSAT-P incorporates a dual-mode feature: the system will be capable of operating as a normal cellular phone when within range of a cellular system or as a satellite phone. It will be possible to make calls to, or receive calls from, any phone on the public switched telecommunications network or another mobile satellite terminal.

94. In addition to providing full duplex voice transmission, INMARSAT-P will support data services at 2.4 kbits. Operational power is to be consistent with microwave safety requirements. An attachable rechargeable battery is being designed for one-hour transmit and 24-hour receive times. The hand-held telephones are expected to be priced at approximately $1,500 (for dual mode model). A single-mode (satellite only) model is also planned which will be marginally smaller and cheaper.

95. INMARSAT eliminated the use of LEO satellites for use in the INMARSAT-P project because of the substantially higher capital costs this would entail. The organization is now in the process of determining whether the flexibility and reach of a constellation of spacecraft in MEO will be simpler and less expensive to operate than a system with several larger satellites in geostationary orbit. For an intermediate circular orbit at an altitude of about 10,300 km, INMARSAT is studying a constellation of 12-15 satellites to provide global coverage. Each satellite would weigh about two tons.

96. For the geostationary orbit, INMARSAT is considering a five-satellite system, with each satellite weighing about four tons. But because 12-15 satellites in MEO can provide more constant coverage, the service offered by this option is considered superior to geostationary orbit. On the other hand, the likelihood of a launch or in-orbit failure is also greater when spread over a larger number of satellites, which supports the argument for utilizing the geostationary option. Similarly, managing a constellation of 15 satellites, with the accompanying ground hardware, is much more complicated than a similar system with five satellites.

97. Users will be expected to pay approximately $2 per minute for calls with INMARSAT-P. With rare exceptions, the system will not reach people in buildings or otherwise out of the line-of-sight view of a satellite. Each INMARSAT-P handset will average 0.25 watts of power and will operate identically to cellular phones in open flat terrain. That is one important difference between INMARSAT-P and the Iridium system which is designed to be able to be used indoors.

98. The general design concept behind the entire Project- 21 terrestrial network is to make maximum use of the existing terrestrial network trunks and technologies to ensure a cost-effective and flexible network. INMARSAT's Signatories have access to comprehensive terrestrial network trunks, and the majority of international telephony traffic by the year 2000 will utilize fibre optic cables which will offer a flexible, high performance (including low delay) and cost-effective means for routing traffic around the globe.

99. INMARSAT has conducted an extensive market research effort to obtain a deeper understanding of the scale of potential global markets for INMARSAT-P. The results of these studies are helping INMARSAT to refine its assessment of the satellite system's capacity, and the operational and economic performance required for viable hand-held satellite phone services. Potential INMARSAT-P markets are: international roaming; national cellular extension; rural, wireless PSTN extension; smaller maritime vessels; yachts and fishing vessels; short-haul aircraft as well as general and corporate aviation. INMARSAT estimates space segment charges of about $1-$2 per minute for voice communications compared to end-user charges of $5-$6 per minute for current INMARSAT-M services.

TECHNICAL PARAMETERS OF LEO SYSTEMS

CHARACTERISTIC	IRIDIUM	GLOBALSTAR	ODYSSEY	ELLIPSAT	ARIES*	PROJECT 21
OPERATOR	MOTOROLA	LQSS (L51%,Q49%)	TRW	ELLIPSAT	CONSTELLATION C.	INMARSAT
NUMBER OF SATELLITES	66	48	12	12 + 6	48	5 / 12 -15
NUMBER OF PLANES	6	8	3	3	4	1 / 3 / 9
COVERAGE	GLOBAL	GLOBAL	NORTHERN, TEMP	GLOBAL	GLOBAL	GLOBAL
SPACECRAFT/	3-AXIS STABILIZED	3-AXIS	3-AXIS	3-AXIS	3-AXIS	TBD
SATELLITE TYPE	LOCKHEED BUS	STABILIZED	STABILIZED	FAIRCHILD	STABILIZED	TBD
ALTITUDE (KM)	780	1389	10354	426 X 2903	1020	36000/10355
ORBIT	CIRCULAR	CIRCULAR	CIRCULAR	ELLIPTICAL	CIRCULAR	----------
INCLINATION (°)	86,4	52	55	63,4	90	0 / 50, 7 / 55
TYPE OF OPERATION	BYPASS	1 LINK TO PSTN	1 LINK TO PSTN	1 LINK TO PSTN	1 LINK TO PSTN	1 LINK TO PSTN
NUMBER OF BEAMS PER SATELLITE	48	6	37*	8	7	109 / 61
BEAM SIZE (KM)	700	980 X 5900	800 X 4000	3600	1700	?
BEAM FOOTPRINT (KMSQ)	216K-445K	1996 K	509742K	9700K	800K	?
SATELLITE MASS (KG)	700	222	1463	240 - 360	130	?
POWER (WATT)	1369	900	2700	800	270	?
LIFE TIME (Y)	5	7,5	10	5	5	?
COMM PAYLOAD	ON BOARD PROC	BENT PIPE	BENT PIPE	BENT PIPE	BENT PIPE	BENT PIPE/ ON BOARD PROC
MODULATION	FDMA/TDMA	FDMA/CDMA	CDMA	CDMA	CDMA	SCPC/TDMA/CDMA
USER LINKS	L/L	S/L	S/L	S/L	S/L	S/L
FEEDER LINKS	Ka BAND	C BAND	Ka BAND	C BAND	C BAND	TBD
INTERSATLINKS	2	NA	NA	NA	--	?
SYSTEM COST (BILLION US $)	3,4	1,2	1,2	0,45	0,4	1,7 -- 2,2
USER-TERMINAL MARKET	HAND-HELD WORLD TRAVELLER MOBILE-MOBILE	HAND-HELD EXTENSION OF CELLULAR	HAND-HELD EXTENSION OF CELLULAR	HAND-HELD EXTENSION OF CELLULAR	HAND-HELD EXTENSION OF CELLULAR	HAND-HELD COMBINATION
COST PER MINUTE ($)	3	0,3 + PSTN	0,65 + PSTN	0,5 + PSTN	-- + PSTN	2
MAX. CH. CAPACITY (CONUS)	9000	5000	4800	1210	420	
SATELLITE/GATEWAY	4	--	--	3	3	
ANTENNA/GATEWAY	MIN 3	MIN 3	MIN 3	3	3	
SERVICES	VOICE, DATA, MESSAGE	VOICE, DATA, MESSAGE	VOICE, DATA, MESSAGE	VOICE, DATA, MESSAGE	VOICE, DATA, MESSAGE	VOICE, DATA, MESSAGE (?)
OPERATIONAL DATE	'98	'98	'98	'96	--	--
CUSTOMER BASE (YEAR 2000)	3 M	--	--	0,6 M	--	--
MAX. ONEWAY DELAY (MS)	400	120	6,8-83	180	--	--

* Editor's note: The Aries system is not covered in the technical survey. Information is included here for the benefit of readers.

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